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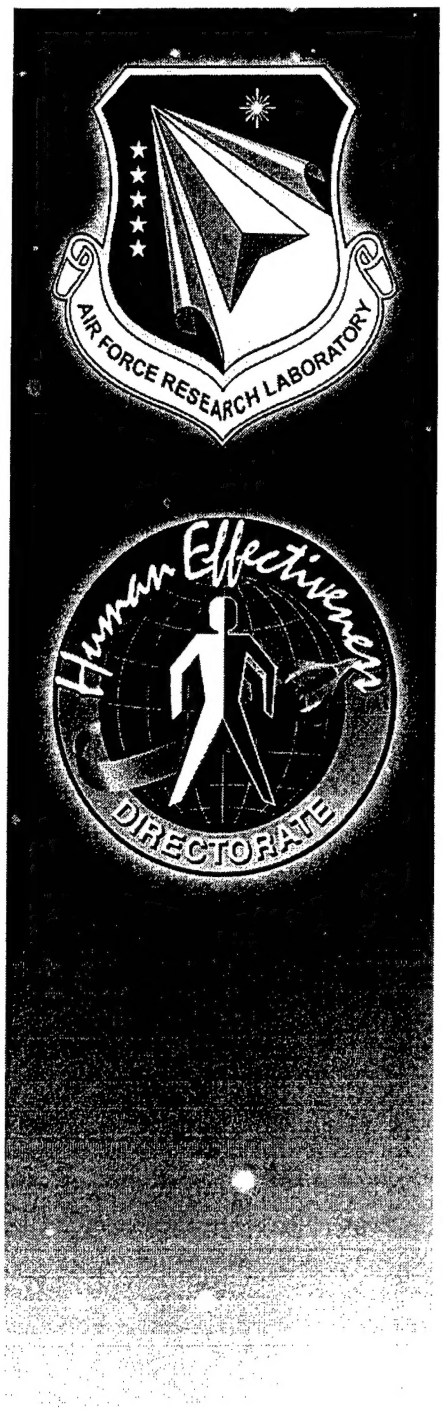

United States Air Force Research Laboratory

THE EFFECT OF CAFFINATED TUBE FOOD ON COGNITIVE PERFORMANCE DURING FATIGUE/CIRCADIAN DESYNCHRONOSIS

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14. ABSTRACT
This report describes the approach and initial results of an investigation of 12 USAF Pilots to determine whether moderate doses of caffeine formulated in tube foods can enhance cognitive vigilance performance in a laboratory study designed to simulate the cognitive demands of a nighttime 10-hr U-2 mission.

15. SUBJECT TERMS
Pilot Fatigue, Sustained Operations, Caffeine, Circadian Rhythm U-2, Performance Enhancement

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Summary

Rationale: Performance sustaining tools are needed to meet demanding mission requirements safely and effectively during sustained and surge operations that superimpose circadian rhythm effects on fatigue in aircrews. Many of the operational tasks that U-2 pilots conduct require sustained vigilance and utilize both visual and auditory modalities. Focus groups conducted with operational U-2 pilots suggest that they have difficulties maintaining the required levels of alertness during many missions and pilot sleep loss is often unavoidable in U-2, as in other military aviation operations. Tube foods are the only foods that can be consumed during a U-2 mission. Caffeine has been demonstrated to be a safe and effective strategy to enhance cognitive performance in numerous military and civilian studies. *Objective*: To determine whether moderate doses of caffeine included in tube foods enhance cognitive, vigilance, and basic simulated pilot performance in a laboratory study designed to simulate the cognitive demands of a U-2 mission. *Methods:* Volunteer participants were 12 healthy USAF male pilots from the San Antonio Area. The study used a double-blind, two-factor, repeated-measures design. Assessments of each dependent measure included tests for the effects of the factors, tube food (caffeinated or placebo) and time (5 iterations throughout the night). Sleep was not permitted on the test nights. One tube of tube food (caffeinated (200 mg) or placebo) was consumed at 2345 and one tube at 0345. On the day of each test, participants arose from sleep no later than 0700 and completed five two-hour testing blocks from 2200 to 0800 the next morning. Flight performance parameters were measured using a desktop computer flight simulator. Mood and self-assessment questionnaires and cognitive and vigilance performance were measured across test sessions and between conditions to assess the interactive effects of fatigue and caffeinated tube food. At the end of each testing session, the participants were administered a questionnaire on side effects, subjective fatigue and self-assessment of well-being. *Results:* In general, the cognitive performance and mood data supported the hypothesis that caffeinated tube food would attenuate the performance decrements associated with fatigue (both sleep loss and circadian disruption). There were statistically significant drug differences for multiple measures of each performance task. The two doses of 200mg of caffeine in the tube food was sufficient in this study to attenuate a majority of the fatigue-induced performance decrements and, in some cases, even improve performance beyond baseline levels, particularly at the 0000 and 0200 time points. *Conclusions:* Two doses of 200mg caffeinated tube food maintained cognitive performance representative of U-2 long-duration mission tasks at or near baseline levels for a 10-hour period overnight in a group of 12 qualified USAF pilots. Side effects were minor and not different between placebo and caffeine conditions. Based on the results from this investigation, caffeinated tube food may be an effective tool for sustaining cognitive and vigilance performance during extended and night-time U-2 operations.

Introduction

The objective of this study was to determine whether moderate doses of caffeine formulated in tube foods could enhance cognitive performance in a laboratory study designed to simulate the cognitive demands of a U-2 mission. Tube foods are the only foods that can be consumed during a U-2 mission and are prepared by the DoD's combat feeding program at Natick Labs. The Natick Combat feeding program has been tasked to provide the U-2 program with tube foods that enhance performance. AFRL/HEPF, in collaboration with USARIEM, was asked by the AF Food Service Directorate of Operations to validate whether the caffeine-containing tube foods produced by Natick Labs enhance vigilance and cognitive performance (Miller, 2002).

The adverse effects of sleep loss on cognitive function that result from continuous/sustained operations are well documented (Krueger, 1991; Miller and Mackie, 1980). In addition, even in rested warfighters that are required to maintain alertness for long periods of time, key aspects of cognitive performance, in particular vigilance, significantly deteriorate (Johnson, 1991; Johnson and Merullo, 1996). One strategy that can be employed to mitigate, in part, such decrements in cognitive performance is the administration of the food component/drug caffeine. Caffeine has been demonstrated to be a safe and effective strategy to enhance cognitive performance in numerous military and civilian studies (for recent reviews, see Lieberman, 2001; Smith, 2002). Its applicability to a wide range of military situations has been endorsed repeatedly by an independent scientific advisory board, the Committee of Military Nutrition Research (CMNR), National Academy of Medicine (Marriott, 1994; CMNR, 2001). (The National Academy of Medicine is the medical arm of the National Academy of Sciences).

It is well established that caffeine enhances cognitive performance in rested and sleep-deprived volunteers. In rested volunteers the effects of caffeine are largely limited to cognitive tasks that require sustained attention, particularly vigilance (for recent reviews, see Lieberman, 2001; Smith, 2002). These beneficial effects of caffeine are present across a wide range of doses (32 –600 mg) and are independent of sensory modality, having been repeatedly observed to be present in both visual and auditory vigilance tasks (Lieberman et al.., 1987; Johnson, 1991; Fine et al., 1994; Johnson and Merullo, 1996; Amendola et al., 1998). Many of the operational tasks that U-2 pilots conduct require sustained vigilance and utilize both visual and auditory modalities. Focus groups conducted with operational U-2 pilots suggest that they have difficulties maintaining the required levels of alertness during many missions. Pilot sleep loss is often unavoidable in U-2, as well as other military aviation operations. In fact, the USAF Safety Center has noted pilot fatigue is a causal or contributory factor in Class A mishaps costing the Air Force approximately $54M annually in personnel, weapon system, and property losses (USAF Safety Center, 2002).

In sleep-deprived individuals, the beneficial effects of caffeine generalize to a wide variety of cognitive tasks, in addition to enhancing vigilance. For example, in a study conducted with sleep deprived volunteers at the Walter Reed Army Institute of Research (WRAIR), doses of 150, 300, and 600 mg of caffeine per 70 kg of body weight significantly improved several aspects of cognitive performance (Penetar et al., 1993; 1994) without producing any adverse effects. Caffeine's beneficial effects have been documented in various simulated military scenarios. For example, Johnson and colleagues (Johnson, 1991; Johnson and Merullo, 1996) demonstrated, in a simulated sentry duty paradigm, that 200 mg of caffeine enhanced performance in rested volunteers. In that study, and others, these investigators used a rifle marksmanship simulator and subjects engaged in a simulated sentry duty task for several hours. In these studies 200 mg of

caffeine improved speed of target detection with no reduction in firing accuracy (Johnson, 1991; Johnson and Merullo, 1996).

In a study designed to assess caffeine in highly stressful, combat-like conditions, Lieberman et al., 2002, studied sleep deprived and environmental stressed volunteers (SEAL trainees during Hell Week), and demonstrated that caffeine enhanced vigilance and other aspects of cognitive performance. In that study, caffeine in doses of 100, 200 and 300 mg were tested and no adverse effects on a task requiring fine motor control (marksmanship), or on mood states such as anxiety were observed (Lieberman et al., 2002). The optimal dose of caffeine in those circumstances was judged to be 200 mg. This is the same dose present in most over-the-counter alertness-enhancing products and is approved by the FDA for this application.

The results of this investigation will be used to validate the usefulness of performance-enhancing foods in military operations, and will provide information on how to more effectively administer these foods. Specifically, in the U-2 environment, many of the operational tasks that U-2 pilots conduct require sustained vigilance and utilize both visual and auditory modalities. Performance sustaining tools are needed to meet demanding mission requirements safely and effectively during sustained and surge operations that superimpose circadian rhythm shifting on fatigue in aircrews.

The study hypothesis was that vigilance, cognitive performance, and basic flight skills would be impacted adversely in unaided subjects (i.e., placebo condition) by the interactive influences of fatigue and circadian nadir. The corollary hypothesis was that this negative impact on vigilance, cognitive performance, and basic flight skills would be attenuated in subjects ingesting caffeinated tube food under the same experimental conditions.

Methods

Participants

12 male USAF pilots (11 T-38 pilots and one F-16 pilot) were recruited from local Air Force installations. See Table 1 for demographic characteristics. Recruiting was accomplished by contacting previous pilot volunteers and through word of mouth. Those volunteers who met the study qualifications (a current Class III Flight Physical, no sleep disorders, not taking prohibited medication, no heavy caffeine or alcohol use) completed all data collection at the Fatigue Countermeasures Lab located on Brooks-City Base in San Antonio, TX. All participants attended a study information and briefing meeting where they were briefed on the important elements of the protocol and read the informed consent document (ICD) approved by the Brooks City-Base and USAF Surgeon General's Human Use Committee (protocol no. FBR-2003-30H). After each participant read the ICD, had all questions answered and agreed to all the conditions, the participant signed the ICD.

Table 1: Participant Demographics

	Mean	**Std. Dev.**	**Min**	**Max**
Age (yrs.)	36.4	7.3	26	45
Weight (kg)	80.0	8.6	70.8	97.5
Height (cm)	178.1	6.5	167.6	188.0

Experimental Design

The experiment used a repeated measures design with two within-subject factors: drug condition (caffeine or placebo) and time (5 two-hour test blocks). Each subject received both drug conditions, spaced by at least one week, with the order of presentation being randomized and counterbalanced. In addition, participants and investigators were blinded to the order of presentation.

Data Collection

Each participant completed three, three-hour, training sessions prior to the two nights of actual testing, which provided for stable and consistent performance for each of the cognitive and physiological test measures. Also, training on the desktop flight simulator was provided to familiarize participants with the aircraft displays and characteristics. Each imbedded measure within the flight performance required very little training, more time was spent on understanding how to read and interpret display features.

One week prior to each testing session participants were provided wrist activity monitors to measure sleep quality and quantity. On the morning of each testing session, participants were instructed to awaken no later than 0700 hrs. Participants were then asked to perform their normal daily activities, but refrain from napping at any time. At 2130 hours the participants traveled to the Fatigue Countermeasures Lab by a pre-arranged taxi. For each night of testing participants completed five testing blocks that occurred at 2200 hrs (baseline trial), 2400 hrs (first dose), 0200 hrs, 0400 hrs (second dose), and 0600 hrs (Table 4). Each dose of tube food,

contained either chocolate pudding and 200 mg of caffeine or chocolate pudding alone. These doses were consumed at 2345 and 0345 immediately prior to the second and fifth test blocks, respectively. Participants were monitored at all times to prevent napping during the testing sessions. During each test block participants performed the desktop flight simulator task, mood survey, symptom questionnaire, as well as cognitive and vigilance tasks (Table 5).

Table 2: Testing routine across the training and testing days

Time of Day	Visit 1 Training	Visit 2 Training	Visit 3 Training	Visit 4 Testing A	Visit 5 Testing B
1800	Training	Training	Training		
1900					
2000					
2100					
2200				Test Block #1 *TUBE FOOD #1*	Test Block #1 *TUBE FOOD #1*
2300					
2400				Test Block #2	Test Block #2
0100					
0200				Test Block #3 *TUBE FOOD #2*	Test Block #3 *TUBE FOOD #2*
0300					
0400				Test Block #4	Test Block #4
0500					
0600				Test Block #5	Test Block #5
0700					
0800				Release	Release

Table 3: Test Block

Test	Time (min)
Cognitive Tests	20
FPASS	20
Vigilance	30
POMS	2
Subjective fatigue	2
Symptoms survey	2
TOTAL Time	**106**

Performance Tests/Survey Instruments

Cognitive Tests

Test Battery Selection. The tests used to measure cognitive performance in this study were chosen by the Test-Matrix, or T-Matrix, method. The T-Matrix is comprised of two dimensions, 1) the

cognitive processes listed in Table 1, and 2) twenty tests that are programmed into a test "armory." The cells in the matrix contain expert ratings (0-9) of the degree to which each test probes each cognitive process as determined by a Subject Matter Expert (SME).

Once the cognitive demands of a particular job are identified and criticality ratings are assigned, these numbers become multipliers in the T-Matrix. The criticality ratings of each cognitive process required throughout the U-2 mission were multiplied by the rating of the degree to which each test probes specific cognitive processes. The sum of the products determined which tests would be included in the U-2 test battery. This process was carried out using only a single SME, located in San Antonio, TX, due to limited time availability. The SME selected was an Air Force Lieutenant Colonel who had flown the U-2 aircraft from 1996 to 2002 and was serving as the Director of Flying Operations for an operational unit. His experiences with operational missions in Kosovo, Afghanistan, and Iraq proved invaluable throughout this process. The following is a brief summary of the demands encountered during typical U-2 missions:

> Most missions were 6-8 hours in length with the longest in Afghanistan, 11 hours. With oxygen pre-breathing (1 ½ hours) the day is really closer to 14 hours. During high alert, missions are flown 24/7, 2/3 during the day, 1/3 at night. Pilots wear pressure suits that are very bulky, making fine motor movement very difficult. Movement is also minimized at altitude because moving joints can lead to the bends in the active joint. Pilots complete tasks slowly to avoid the bends. The cabin is pressurized to only 28,500 feet and fatigue is a big factor. Prior to oxygen pre-breathing, decompression illness was a big factor even on 100% oxygen. Breathing 100% oxygen probably causes much of the fatigue they experience. It is not uncommon to sleep nearly 12 hours after a long mission. Pilots are DNIF for 24 hours for missions greater than 9 hours. Missions are generally boring once on station and the autopilot is activated. Takeoff and landing (1-hour preparation) are very difficult in the aircraft due to restricted cockpit visibility, large wing span, and control delay. Dynamic re-tasking has become evermore frequent, especially during war. When fatigued, it can take five minutes to key in five waypoints. The U-2 cockpit is a warm, quiet, cozy environment and can lull the pilot into a false sense of security and contribute to fatigue.

Subsequent to the extensive discussion of the required activities, the SME was asked to comment on each cognitive process in the list shown in Table 2. His comments on each factor are presented in the table.

Table 4: Subject Matter Expert Elaboration on a Comprehensive List of Cognitive Processes.

Cognitive Process	Subject Matter Expert Elaboration on Cognitive Processes
Visual-Motor Control	This is used during takeoff and landing mainly. Also used to configure the plane prior to activation of the autopilot for following pre-planned coordinates. With the onset of fatigue, focusing the eyes on objects takes more time and he loses the ability to use the sound and feel of the airplane to know what is happening to it.
Time/Velocity Estimation	This is not done visually, but rather computationally for altitude changes and for planning destination arrival parameters (heading, speed, etc.). We rely on this skill when avoiding incoming missiles.
Decision Making	Integrates information on threats, waypoint locations, orientation at way point/targets and fuel requirements to make a decision concerning approach paths or whether a mission element can be achieved. We must decide how best to avoid incoming missiles when under fire. We often receive dynamic re-taskings from AWACS and have to integrate information to determine best options and feasibility of carrying out the order. AWACS are often unaware of onboard fuel and restricted fly zones.
Planning/Problem Solving	Dynamic re-tasking often requires the pilot to plan an approach to the first way point because his position at the time of receiving the request is not taken into account by the requesting agent.
Spatial Manipulation	Flying an aircraft is nearly the definition of spatial manipulation.
Math Functioning	Frequently used to compute rates of decent for achieving a specific orientation to at target/waypoint. This cognitive skill is one of the most difficult tasks to complete when fatigued.
Language/Semantics	Foreign controllers are often difficult or impossible to understand because they use ungrammatical English. The agencies of the joint services use service-specific phraseology that is often difficult to interpret.
Task Multiplexing	Four radios may be active simultaneously and all requiring some response. Each is likely related to a different domain of information (Intel, AWACS, local controller, etc.). Although we can only respond to one at a time, all must be eventually addressed.
Procedural Long-Term Memory	Checklists are often unavailable (due to poor lighting and/or pressure suit restrictions) and must be recalled from memory. A recent crash may have been caused by the pilot failing to remember checklist procedures because his suit was inflated and he was unable to view the checklist during an emergency landing.
Episodic Long-Term Memory	Not used frequently.
Sustained Attention	Take offs and landings require sustained focused attention to details. The U-2 is one of the most difficult aircraft to land in the inventory. Additionally, there is difficulty in maintaining a narrow airspeed window between stall speed and mach limit at altitude.
Divided Attention	Occasionally one must divide ones attention among multiple tasks.
Selective Attention	Having several (3-4) radio frequencies active occasionally requires the pilot to select one and

	cognitively block the others to accomplish a problem.
Problem Sensitivity	Pilots have a periscope to zoom in on a potential target and, if important, request a change to the targeting of their aircrafts sensors.
Cognitive Flexibility	Required in determining the best route for return-to-base—integrating fuel, crosswind limits, available runways, and ceilings.
Attentional Capacity (Working Memory)	Because of difficulties in writing and reading in the pressure suit, information is often held in memory for several seconds or minutes. Pilots occasionally request a rebroadcast of the information, "say again." Pilots will use a grease pencil to record the incoming information writing on anything, mission display, screen, canopy, etc.
Situation Awareness	AWACS and other agencies provide much information that they use to update their awareness of what is around them, what threats they face, the location of a tanker, escort fighters and jammers. Pilots must verify correctness of information and integrate with onboard information for a "total" picture.

As most jobs or tasks require different degrees of each cognitive process the most important part of this analysis is to indicate the degree to which a job or task requires each specific cognitive process. These ratings differentiate one job from another. For this study several cognitive psychologists rated each cognitive skill for criticality, and for the relative duration it would be used in a typical mission. Table 3 shows the consensus ratings. In this table ratings for criticality and duration ranged from 1 to 4, and the final rating was simply the sum of the two factors. In practice, any such ordinal system could be used, or only a "criticality" factor might be rated, depending on the particular application. It was decided that, for this study, any combined rating above and including 5 would emerge as a "critical" process.

Table 5: Cognitive Functions for U-2 Pilots

Cognitive Function	**Criticality**	**Duration**	**Rating**
Visual-Motor Control	4	3	**7**
Time/Velocity Estimation	4	2	**6**
Decision Making	3	1	4
Planning/Problem Solving	3	1	4
Spatial Visualization	4	3	**7**
Math Functioning	3	2	**5**
Situation Awareness	4	4	**8**
Language/Semantics	1	1	2
Task Multiplexing	2	2	4
Procedural Long-Term Memory	2	2	4
Episodic Long-Term Memory	1	1	2
Sustained Attention	4	4	**8**
Divided Attention	3	2	**5**
Selective Attention	3	2	**5**
Attentional Capacity – Working Memory	3	2	**5**
Problem Sensitivity	2	2	4
Cognitive Flexibility	1	2	3

This analysis produced final ratings of criticality for the U-2 pilot that ranged between 3 and 8. Nine of the 17 cognitive processes reached the criterion. However, it was noted that while all three of the "attention" factors reached criterion, the "sustained attention" factor clearly dominated. Therefore, this was the only one that was retained. The remaining critical cognitive processes of the U-2 pilot identified for further study were *Visual Motor Control (7), Time Velocity Estimation (6), Spatial Visualization (7), Situation Awareness (8), Sustained Attention (8), and Working Memory (5).*

The final cognitive test battery duration (not including the Scanning Visual Vigilance Test) was 18-20 minutes for each administration. Each individual test lasted up to three minutes. The battery used tests similar to batteries we have used in the past to monitor fatigue (Torsvall et al., 1989) and the effects of stimulants (Bleiburg et al., 1993) and consisted of the following tasks:

1. Code Substitution – short term memory
2. Adaptive Tracking – attention / visual motor control
3. Relative Motion – time velocity estimation / visual motor control / working memory
4. Precision Timing – time velocity estimation / visual motor control
5. Motion Inference – spatial visualization / situation awareness / time velocity estimation
6. Continuous Memory – working memory
7. Manikin Task – working memory / spatial visualization
8. Match to Sample – spatial visualization
9. NovaScan™ - (complex cognitive task) working memory / spatial visualization / situation awareness
10. Visual Vigilance – sustained attention
    Scanning Visual Vigilance Test - Volunteers were tested on a visual vigilance test (Lieberman et al., 1998) used previously to detect the effects of moderate doses of caffeine on vigilance (Fine et al., 1994; Lieberman et al., 2002). The task required the volunteer to detect a faint dot that randomly appeared in an arbitrary point on the screen for two seconds. Individual volunteers' visual thresholds were obtained prior to actual testing. Average presentation of the dot occurred once a minute. Upon detection of the presented stimulus, the volunteer pressed the space bar on the keyboard as quickly as possible. The computer recorded whether or not a stimulus was detected and the response time for detections. Responses made before or after stimulus occurrence were recorded as false alarms.
11. Flight Performance Assessment Simulation System (F-PASS) – (complex cognitive task)
    Testing of selected aviation relevant skills was conducted first using a desktop computer

equipped with simulated flight controls employing Flight-Performance Assessment Standardized System (F-PASS) software (O'Donnell and Moise, 1998). Performance measurements included the following: 1) ability to maintain altitude, heading and airspeed within acceptable limits, 2) ability to attend to multiple simultaneous tasks, 3) ability to recognize position in space, 4) a test of vigilance assessing the ability to detect a slowly deteriorating situation, 5) ability to recognize a stimulus and perform a motor corrective action, 6) ability to immediately and remotely recall instructions, 7) ability to maintain positive mood and communicative relationships measured via a mood assessment tool.

Demographic Caffeine and Tobacco Use Questionnaire

A demographic caffeine and tobacco use questionnaire was administered once during the practice sessions to obtain basic descriptive data such as age, height, weight, etc. Background questions regarding demographic information such as military rank, ethnic group, and time on active duty, etc. were also obtained. In addition, prior and current levels of caffeine consumption and tobacco were obtained.

Profile of Mood States (POMS) Questionnaire

The POMS is a computer-administered inventory of subjective mood states (McNair et al., 1971). Once per test block, the participant rated a series of 65 mood-related adjectives on a five-point scale. Previous research has shown that the adjectives factor into six mood sub-scales (tension, depression, anger, vigor, fatigue, and confusion).

Assessment of Sleep-Wake Cycles

Actigraph. The Actigraph resembled a wristwatch externally and was worn in a similar manner. A small accelerometer systematically recorded the individual's movement over time, both while awake and asleep. The data provided an effective means to identify sleep behavior patterns (Cole, 1992). Participants wore the actigraphs for a week prior to the first data collection to help assure that they did not have atypical sleep activity patterns. They also wore actigraphs during the days between test sessions.

Activity Log. The activity log was used to provide sleep histories and subjective fatigue ratings for each participant. Participants indicated their fatigue state every two hours and when they went to sleep and awoke. The log was used for a week prior to the first data collection to help assure that they did not have atypical sleep activity patterns. They also completed the log during the weeks between test sessions and for a week after the final test session.

Symptoms Questionnaire

During each test block participants were asked to circle the appropriate rating (0 = none, 1 – 3 = slight, 4 – 6 = moderate, 7 = severe) to each of the 64 symptoms listed that they experienced. In addition participants were asked once at the end of the last test session for each condition whether they thought they received caffeine.

Caffeinated Tube Food

The caffeine administered in this study (200 mg) was equivalent to approximately two cups of coffee. A recommended dose of caffeine when it is given as an over-the-counter (OTC) "stimulant" (e.g. Vivarin) is 200 mg. every 3- 4 hours. The total dose of 400 mg administered in this study (two 200 mg doses over 4 hours) was therefore within normally accepted limits. It was also well within the range of normal human caffeine consumption from foods.

The use of caffeine has occasionally been reported to be associated with the following symptoms: diarrhea; dizziness; fast heartbeat; irritability, nervousness; nausea; tremors; trouble sleeping; and vomiting. A number of studies have been conducted with caffeine employing higher doses then proposed here with no significant adverse effects observed. It has been suggested that caffeine administration results in dehydration but a recent, thorough review found no evidence of such an effect (Armstrong, 2002). Non-caffeinated liquids were consumed during break times in this investigation. In higher doses caffeine can cause slightly elevated blood pressure. Any individual with known hypersensitivity to caffeine, other xanthines or who is hypertensive or suffering from any cardiovascular disease was excluded from participation.

Data Analysis

Prior to statistical analysis, the data was baseline-adjusted to counter any potential change in a participant's performance from the first experimental session to the second experimental session. This was accomplished for each outcome measure by subtracting a participant's data at baseline (Day 1 2200 hrs) from the data at each of the five trials. For each outcome measure, a repeated measures analysis of variance (ANOVA) was performed to test for significant drug main effects, time main effects, and drug by time interaction. A Huyhn-Feldt adjustment was made for variables that failed Mauchly's Test of Sphericity. When significant effects were detected in the ANOVAs, post-hoc simple effects tests were used to compare the change from baseline under caffeine with the change from baseline under placebo, at each time point, separately. In addition, the mean at each time point was compared back to the mean at baseline for the placebo and caffeine groups, separately.

Power Analysis

All testing was performed at the 0.05 confidence level. The primary goal of the study was to determine whether there was a difference in the change over one night of sleep loss between placebo and caffeinated tube food conditions. Consequently, our power analysis was based upon the specific *post-hoc* comparisons of the two drug conditions. The sample of 12 complete data sets provided a 90% chance (power) of detecting a difference that is about one standard deviation of the difference in magnitude (i.e., effect size of 1.0).

Results

All 12 participants completed the study. Any mention of statistical significance refers to an alpha level of .05. Due to the usual problems associated with data collection, a small amount of data was lost (less than 2%). Prior to analysis, we estimated each missing point based on the average percent change of the other data available for that same drug condition and time point.

Table 7 contains the descriptive statistics and statistical test results for all of the performance and affect variables recorded in this study. For each outcome measure, the baseline mean and standard deviation are shown followed by the mean change (and standard deviation) from baseline at each subsequent time point. The ANOVA results are shown in the last three columns of the table. For those variables where the ANOVA indicated significant effects, superscripts (defined in the table legend) are used to identify significant post-hoc results. Only select variables for which significant effects were observed ($p \leq .05$) are discussed and graphed, below. For each task (e.g., cognitive and subjective) a general description of the results seen for the dependent measures will be given; followed by detailed discussion and graph of a selected measure in the text below.

Cognitive Performance Tests

Code Substitution

For the Code Substitution Test, significant main effects for drug and time, and a drug x time interaction were detected for throughput (correct responses per minute of correct responding), and a significant drug effect was detected for accuracy, mean reaction time correct (MRTC), and standard deviation. For each of these dependent measures, performance under placebo generally degraded from baseline over time while performance under caffeine never dropped below baseline performance. Figure 1 shows the details for throughput.

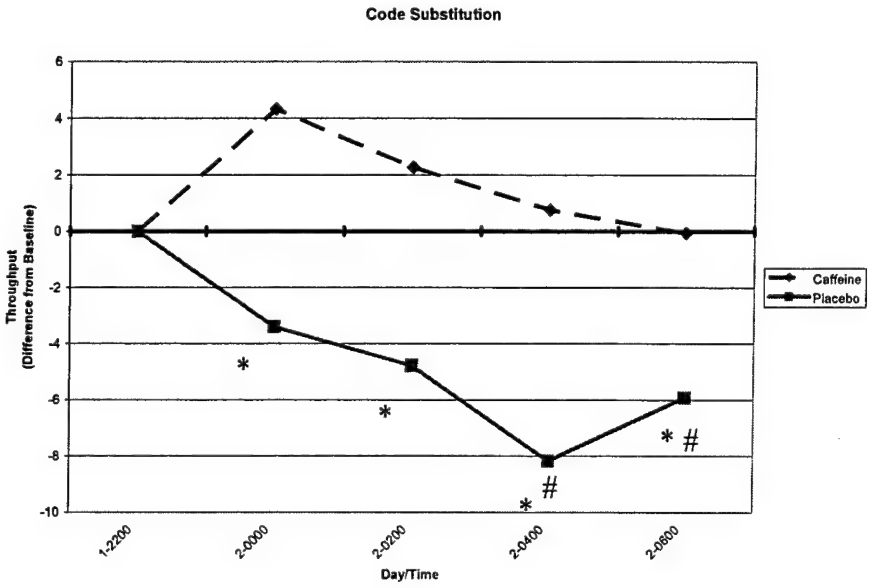

Figure 1: Code Substitution Throughput
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Adaptive Tracking

For the Adaptive Tracking Test, significant main effects for drug and time, and a drug x time interaction were detected for Root Mean Square (RMS) Error. Performance under placebo degraded from baseline over time while performance under caffeine remained near baseline levels until 0600 (Figure 2).

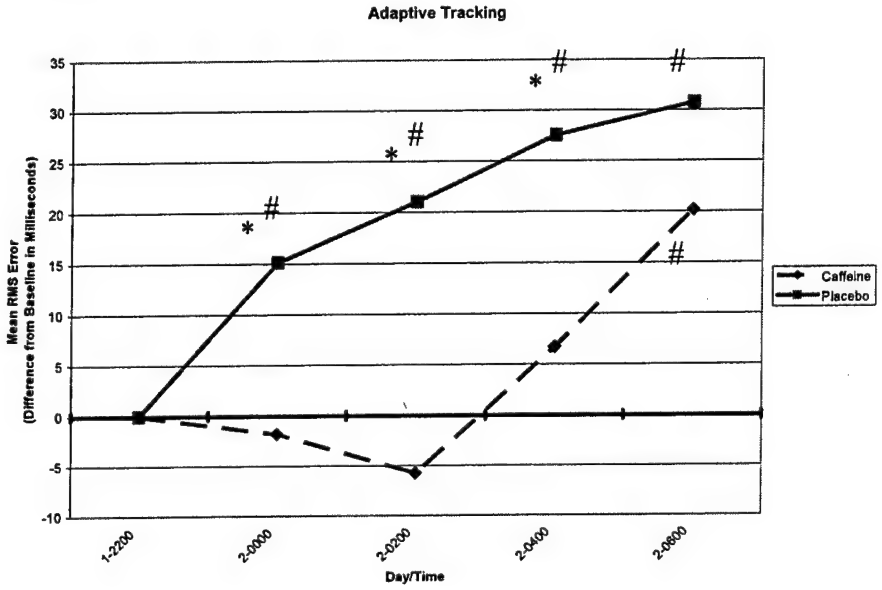

Figure 2: Adaptive Tracking Mean RMS Error
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Motion Inference

For the Motion Inference Test, a significant main effect of drug and a drug x time interaction for mean response time for all responses (MRT All), mean response time for verbal correct responses (MRTVC), Standard deviation of the response times for all responses (SDRT All), and SDRTVC were detected. Performance under placebo generally degraded and became more variable over time while performance under caffeine actually improved or remained near baseline for all successive trials. Figure 3 gives detailed results for MRT All.

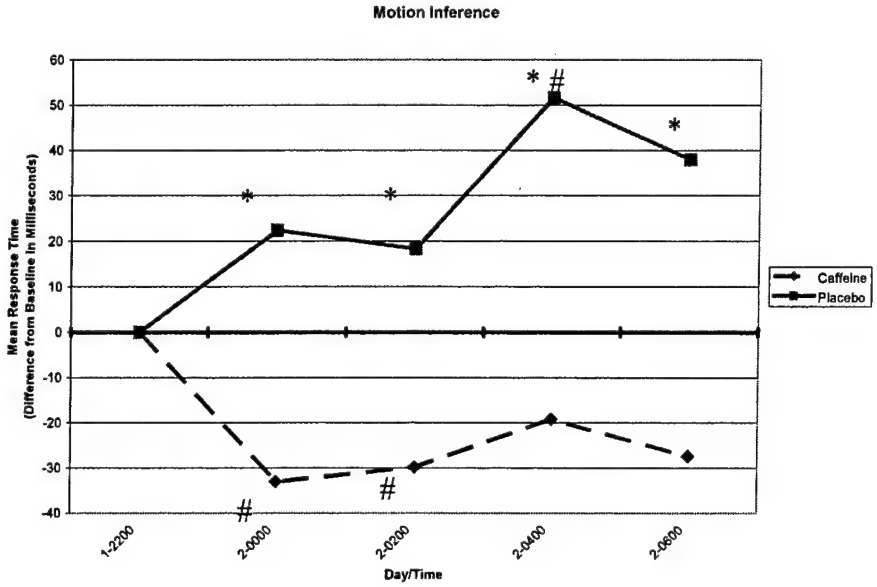

Figure 3: Motion Inference Mean Response Time All
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Manikin Test

For the Manikin Test, a significant drug x time interaction was detected for Percent Correct, MRTC and SDRTC. MRTC also had a significant main effect for drug. Performance under placebo generally degraded and became more variable over time while performance under caffeine actually improved, or remained near baseline for all trials. Figure 4 details the results for MRTC.

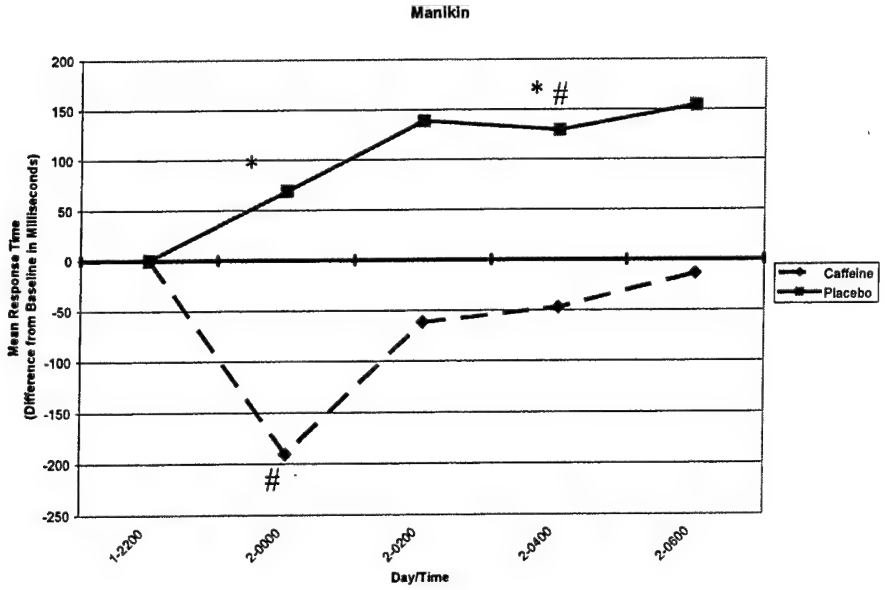

Figure 4: Manikin Mean Response Time Correct
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Match to Sample

For the Match to Sample Test, significant drug x time interactions were observed for MRTC, accuracy, and throughput. In addition main effects for drug were detected for MRTC and throughput. Performance under placebo generally degraded while performance under caffeine actually improved, or remained near baseline for all trials. Details for MRTC are shown in Figure 5.

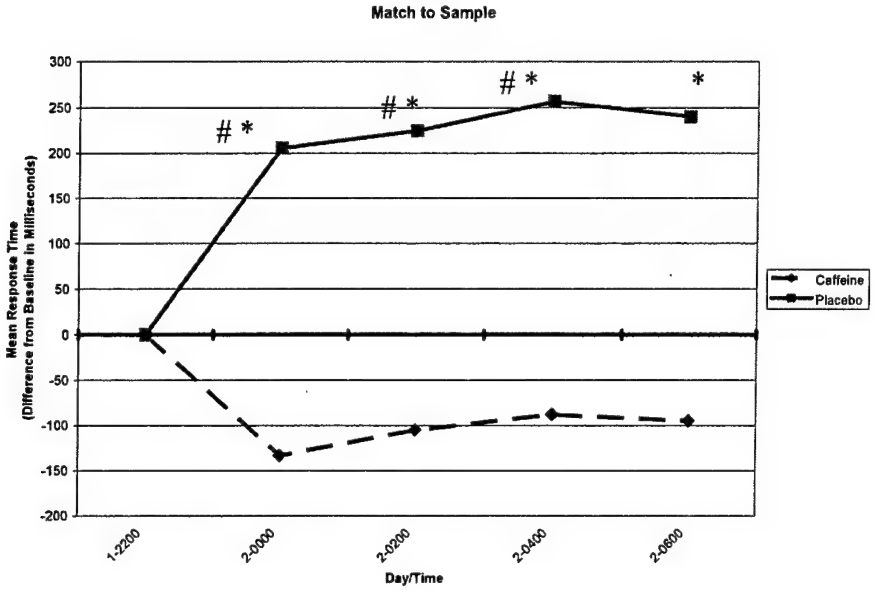

Figure 5: Match to Sample Mean Reaction Time Correct
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Nova Scan

For the Nova Scan Test, significant main effects for drug were detected for Mean Dial Response Time to Transitions (MDRTT) and Mean Response Time to Transitions Total (MRTT). Performance under placebo generally degraded while performance under caffeine actually improved, or remained near baseline for all trials. Figure 6 details the results for MRTT.

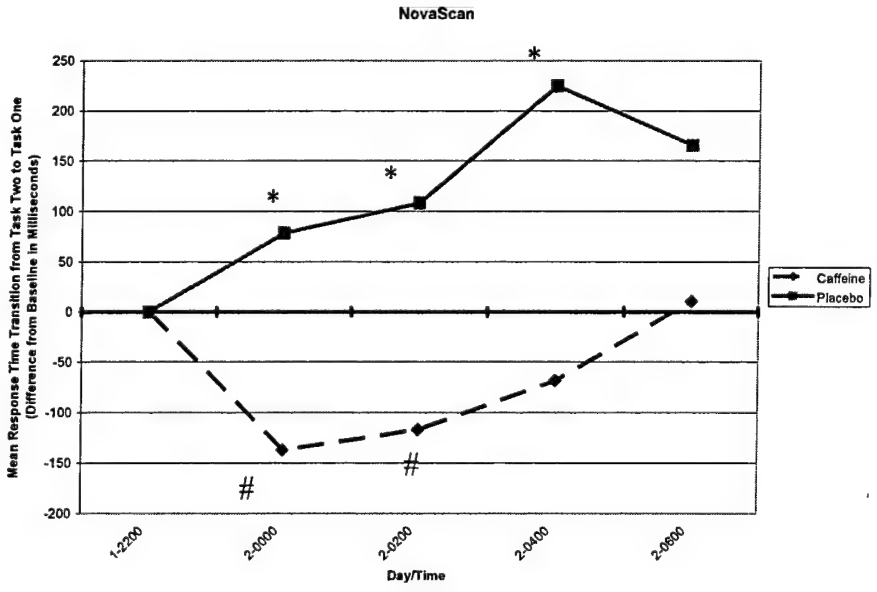

Figure 6: Nova Scan Mean Response Time from Task Two to Task One
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Scanning Visual Vigilance

For the Scanning Visual Vigilance Test, significant main effects for time were detected for the number of Hits (correct responses). The number of hits decreased over time for both conditions, but significant decreases were seen only for the placebo condition (Figure 7).

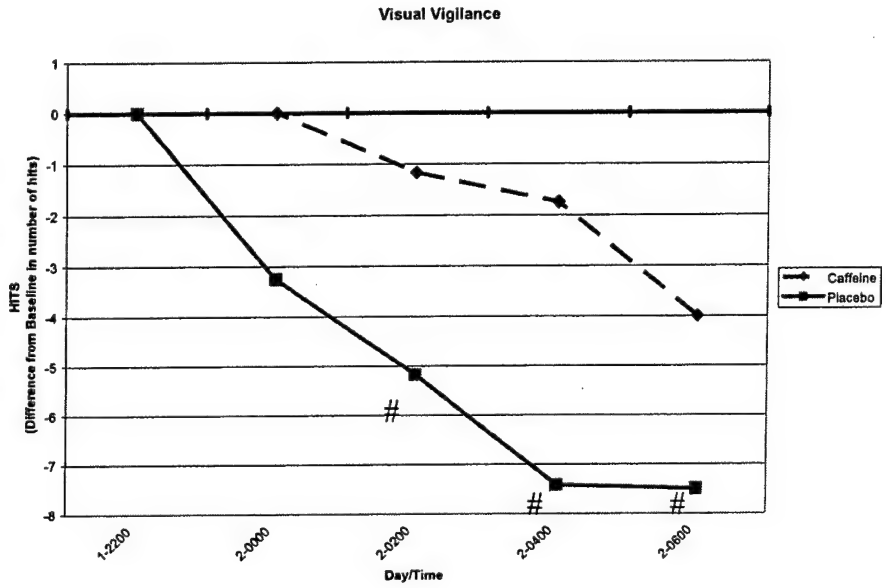

Figure 7: Visual Vigilance Number of Hits
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

High Fidelity Flight Performance Assessment Simulation System (FPASS)

Six different embedded measures of performance in this complex environment were analyzed. In all, four tasks (controlled turn, radar warning receiver, surface to air missile alert, flight path deviation) showed no significant changes throughout the night while two tasks showed significant effects.

Imbedded Math Processing

Significant main effects of drug and trial were detected. Performance under placebo generally maintained baseline levels, while performance under caffeine actually improved for all trials. (Figure 8)

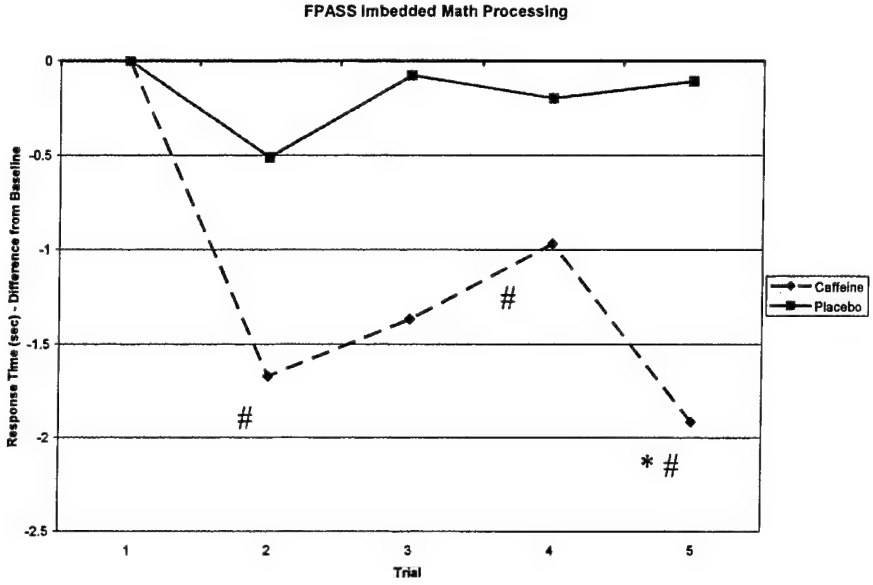

Figure 8: Imbedded Math Processing
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Delayed Radio Frequency Change

A significant main effect of time was detected. However, the response patterns exhibited in Figure 9 do not allow for any meaningful interpretation of these results.

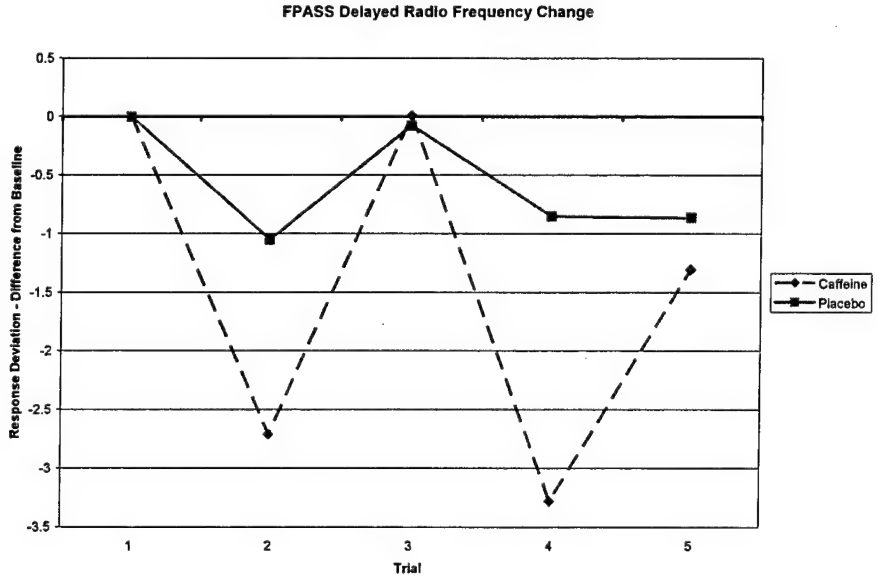

Figure 9: Delayed Radio Frequency Change
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Profile of Mood States (POMS)

For the POMS Test, significant drug x time interactions were detected for the confusion, fatigue, and vigor scales. There were also drug main effects for confusion and fatigue. Performance under placebo generally degraded while performance under caffeine remained near baseline through the first three trials. Figure 10 details the results of the fatigue scale.

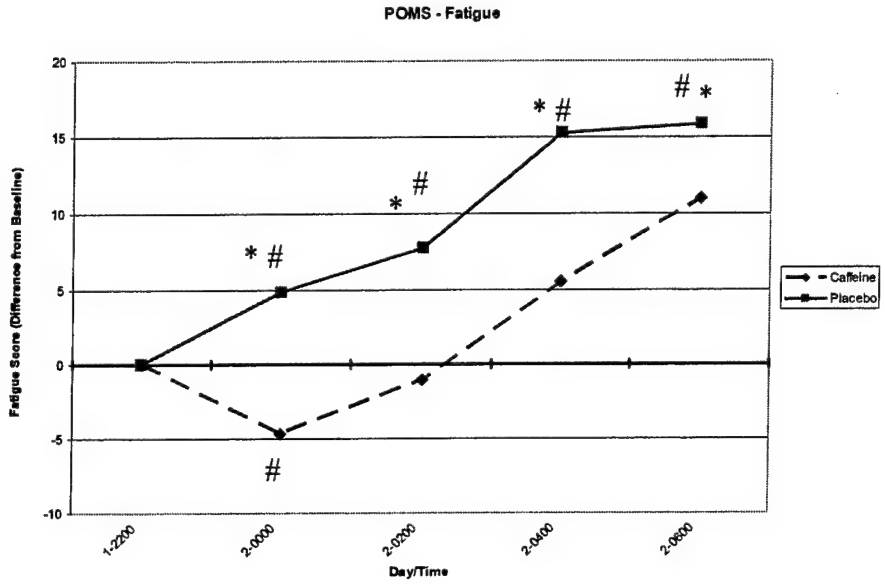

Figure 10: POMS Fatigue Ratings
* significant difference between caffeine and placebo changes ($p \leq .05$)
# significant change from baseline ($p \leq .05$)

Symptom Questionnaire

Although, none of the participants indicated moderate or severe symptoms under the caffeine or placebo condition, there were some indications of slight symptoms under both conditions. Table 6 shows, for each symptom, the number of participants for whom the symptom was worse (though still slight) during the night than it was at baseline. Symptoms that were never reported in either condition have been omitted from Table 6. Due to the relatively small sample size a statistical analysis was not performed on this data. Inspection of the table shows that, generally, distribution of the symptoms was even between the two conditions. One notable exception was the increase in abdomen pain and stomach cramp reports under the caffeine condition.

Table 6: Number of participants for whom the symptom was worse than at baseline

Symptom	Caffeine	Placebo	Symptom	Caffeine	Placebo
Abdomen Pain	3	0	Itching	2	1
Awareness of Breathing	2	0	Loss of Balance	1	2
Chest Pain	1	0	Loss of Coordination	2	6
Confusion	0	1	Memory Loss	0	1
Difficulty Focusing	4	8	Mentally Depressed	0	1
Diarrhea	1	0	Muscle Cramp	1	0
Difficulty Staying Awake	10	9	Nasal Congestion	0	1
Difficulty Concentrating	7	11	Nausea	2	1
Dizzy with eyes Closed	1	2	Nervous	1	0
Dizzy with eyes open	2	3	Numbness	1	0
Drowsiness	8	10	Rash	1	0
Drug feel	2	2	Shortness of Breath	0	1
Eye Strain	2	4	Sore Throat	1	0
Fatigued	9	11	Difficulty Staying Awake	9	11
Frequent Urination	3	3	Stomach Awareness	3	1
Full Headed Felling	0	1	Stomach Cramp	4	1
General Discomfort	3	2	Swelling	1	0
Headache	1	0	Thirst	0	1
Increased Appetite	0	1	Tingling	1	0
Increased Saliva	0	1	Vertigo	0	1
Irregular Heart Rate	1	0	Visual Illusions	1	1
Irritable	3	1			

Table 7: Summary Table of Descriptive Statistics and Statistical Test Results

Test	Variable	Drug	Baseline 2200hr	Change from Baseline at:				ANOVA Results			
				0000hr	0200hr	0400hr	0600hr		Drug	Time	Drug x Time
Code Substitution	Accuracy (%)	caffeine	97.0 3.6	1.6 4.2	.7 2.1	.5 3.9	-.8 5.6	MSE df F p	43.33 (1,11) 6.34 **.029**	30.90 (2,20) [h] 1.84 .186	13.04 (4,44) 1.82 .142
		placebo	98.8 1.9	-2.8 4.7	-1.9 3.8	[b] -4.7 6.9	-3.9 6.5				
	MRTC (msec)	caffeine	1092 201	-63 [a] 118	-43 [a] 88	-1 [a] 61	-7 [a] 106	MSE df F p	21565 (1,11) 15.33 **.002**	14512 (4,44) 2.04 .105	10160 (4,44) 2.21 .084
		placebo	1097 194	59 [a] 148	83 [a] 156	[b] 160 [a] 188	110 [a] 182				
	SDRTC (msec)	caffeine	329 145	-68 150	[b] -87 [a] 115	-48 129	-54 122	MSE df F p	37853 (1,11) 6.06 **.032**	9203 (4,41) [h] 1.06 .387	8768 (4,44) 1.92 .125
		placebo	330 138	7 114	33 [a] 164	66 151	74 175				
	Thruput (# correct/min)	caffeine	54.6 7.8	4.3 [a] 7.3	2.3 [a] 4.0	.8 [a] 4.2	-.1 [a] 7.0	MSE df F p	68.65 (1,11) 15.25 **.002**	23.73 (4,44) 3.36 **.017**	22.67 (4,44) 3.21 **.021**
		placebo	55.4 9.1	-3.4 [a] 5.8	-4.8 [a] 8.8	[b] -8.2 [a] 8.1	[b] -5.9 [a] 7.0				
Match To Sample	Accuracy (%)	caffeine	97.9 3.1	-1.0 4.5	1.0 3.6	-3.1 6.3	[b] -4.2 [a] 6.3	MSE df F p	33.49 (1,11) 0.17 .688	20.33 (4,44) 1.02 .409	19.69 (4,44) 2.82 **.036**
		placebo	95.8 5.5	-1.1 7.1	-2.8 7.1	-1.6 3.9	.3 [a] 4.3				
	MRTC (msec)	caffeine	1310 337	-133 [a] 224	-105 [a] 227	-88 [a] 224	-95 [a] 238	MSE df F p	142348 (1,11) 15.35 **.002**	37987 (4,44) 0.71 .591	30301 (4,44) 4.51 **.004**
		placebo	1201 295	[b] 206 [a] 276	[b] 225 [a] 335	[b] 257 [a] 266	240 [a] 415				
	SDRTC (msec)	caffeine	422 154	-50 203	-24 204	-51 186	-35 233	MSE df F p	118930 (1,11) 4.04 .070	22499 (4,44) .64 .635	30755 (4,44) 1.34 .271
		placebo	389 157	127 232	64 241	112 177	169 301				
	Thruput (# correct/min)	caffeine	47.6 12.5	6.4 [a] 11.9	[b] 5.6 [a] 9.0	2.4 [a] 8.6	-.4 7.6	MSE df F p	195.26 (1,11) 12.06 **.005**	51.40 (4,44) 1.13 .355	39.41 (4,44) 5.47 **.001**
		placebo	49.6 15.4	[b] -6.7 [a] 10.0	[b] -8.8 [a] 11.2	[b] -8.9 [a] 10.0	-5.9 11.5				
Motion Inference	MRTALL (msec)	caffeine	308 52	[b] -33 [a] 43	[b] -30 [a] 45	-19 [a] 73	-27 [a] 69	MSE df F p	5018 (1,11) 13.76 **.003**	2795 (4,44) .71 .591	1192 (4,44) 4.01 **.007**
		placebo	308 93	22 [a] 57	18 [a] 52	[b] 52 [a] 79	38 [a] 81				
	MRTVC (msec)	caffeine	964 230	-67 124	[b] -103 [a] 128	[b] -104 [a] 98	[b] -123 [a] 117	MSE df F p	55683 (1,11) 8.48 **.014**	3818 (4,44) 1.31 .280	6558 (4,44) 6.34 **<.001**
		placebo	915 183	14 85	74 [a] 135	91 [a] 155	51 [a] 97				
	SDRTALL (msec)	caffeine	222 54	-11 55	-17 43	-11 [a] 77	-15 [a] 63	MSE df F p	15588 (1,11) 6.12 **.031**	3836 (4,44) 1.13 .356	2606 (4,44) 2.90 **.033**
		placebo	223 68	49 126	32 72	[b] 74 [a] 100	73 [a] 118				
	SDRTVC (msec)	caffeine	247 131	[b] -61 [a] 94	[b] -66 [a] 95	-49 [a] 97	[b] -73 [a] 95	MSE df F p	8108 (1,11) 8.13 **.016**	22700 (2,21) [h] .94 .403	13969 (2,27) [h] 5.65 **.006**
		placebo	187 84	69 [a] 152	139 [a] 253	129 [a] 250	154 [a] 269				

Notes:
1. Numbers in each cell of the table represent the mean (top) and standard deviation (bottom).
2. [h] Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.
3. Post-hoc significance test results:
   [a] significant difference between caffeine and placebo changes ($p \leq .05$)
   [b] significant change from baseline ($p \leq .05$)

Table7: (Continued)

Test	Variable	Drug	Baseline 2200hr	Change from Baseline at:				ANOVA Results			
				0000hr	0200hr	0400hr	0600hr		Drug	Time	Drug x Time
Manikin	MRTC (msec)	caffeine	1733 294	[b] -191[a] 113	-62 96	-47[a] 162	-14 142	MSE df F p	57094 (1,10) 6.91 **.025**	14463 (4,40) 6.38 **<.001**	11030 (4,40) 3.46 **.016**
		placebo	1761 319	-10[a] 161	12 138	[b]157[a] 231	126 245				
	SDRTC (msec)	caffeine	523 175	[b]-104[a] 104	-47 74	-32[a] 123	32 93	MSE df F	40439 (1,10) 4.62 .057	7632 (4,40) 4.34 **.005**	6117 (4,40) 3.92 **.009**
		placebo	511 221	24[a] 129	37 115	[b]131[a] 160	70 171				
	PCTCorrect (%)	caffeine	97.0 2.6	.3 1.9	-.9 4.1	.7[a] 3.4	.4 3.2	MSE df F p	10.92 (1,10) 4.77 .054	17.58 (2,21)[h] 0.47 .640	5.85 (4,40) 2.91 **.033**
		placebo	96.9 4.0	-1.4 2.9	-.3 2.4	-3.2[a] 5.3	-1.4 3.0				
Visual Vigilance	HITS (# correct)	caffeine	14.25 11.86	.00 8.01	-1.17 5.75	-1.75 9.15	-4.00 6.88	MSE df F p	88.45 (1,8) 3.06 .119	23.97 (4,32) 6.60 **.001**	14.91 (4,32) 1.63 .191
		placebo	18.00 12.39	-3.25 5.33	[b]-5.17 4.95	[b]-7.42 7.49	[b]-7.50 7.25				
Tracking	Control Losses	caffeine	.17 .39	-.17 .39	-.08 .51	.42 1.24	1.17 2.89	MSE df F p	24.89 (1,11) 2.96 .113	18.75 (1,14)[h] 3.32 .082	11.55 (2,20)[h] 0.99 .383
		placebo	1.33 3.08	1.50 3.99	1.58 2.64	2.42 3.94	3.67 7.69				
	RMS error	caffeine	55.19 27.27	-1.82[a] 11.88	-5.74[a] 21.49	6.70[a] 24.80	[b]20.14 24.60	MSE df F p	453.06 (1,11) 14.96 **.003**	274.86 (4,44) 8.66 **<.001**	230.93 (3,31)[h] 3.92 **.020**
		placebo	54.48 23.76	[b]15.12[a] 21.39	[b]21.05[a] 20.43	[b]27.54[a] 22.78	[b]30.74 29.96				
Novascan	MDRTT (msec)	caffeine	954 202	-080 133	[b]-97[a] 109	-62[a] 148	-59[a] 136	MSE df F p	28560 (1,11) 11.53 **.006**	17551 (4,44) 0.63 .644	28805 (2,21)[h] 1.92 .171
		placebo	941 239	96 247	18[a] 143	27[a] 128	85[a] 179				
	MRTT (msec)	caffeine	1908 332	[b]-104[a] 144	[b]-98[a] 112	-55[a] 135	-8 102	MSE df F p	41065 (1,11) 12.94 **.004**	58789 (2,20)[h] .85 .432	40387 (2,23)[h] 1.87 .174
		placebo	1897 332	85[a] 217	67[a] 177	145[a] 302	104 357				
	SDDRTT (msec)	caffeine	289 144	-41 183	-76 141	-36 160	-74 132	MSE df F p	46916 (1,11) 4.20 .065	15758 (4,44) .91 .466	26633 (3,28)[h] 1.38 .271
		placebo	238 123	78 304	-16 128	28 117	88 219				
	SDRTT (msec)	caffeine	625 144	-51 146	-86 120	-49 115	-23 138	MSE df F p	39125 (1,11) 4.53 .057	12540 (4,44) 1.01 .414	10455 (4,44) 1.25 .305
		placebo	584 162	41 172	4 116	77 185	55 190				
Continuous Memory	MRTC (msec)	caffeine	1387 183	-63 145	-74 130	-120 141	-21 205	MSE df F p	49990 (1,11) 1.91 .194	29693 (3,29)[h] .64 .580	12266 (4,44) 2.30 .074
		placebo	1401 260	-47 164	-4 170	50 178	5 301				
	PCT Correct (%)	caffeine	97.1 2.8	.3 2.3	.3 3.7	-.3 4.2	.3[a] 3.7	MSE df F p	69.16 (1,11) 4.81 **.051**	11.30 (4,44) 1.93 .123	11.37 (4,44) 2.33 .071
		placebo	97.9 2.6	-3.4 7.3	-3.5 5.9	[b]-3.6 4.7	[b]-5.5[a] 7.5				
	SDRTC (msec)	caffeine	574 105	-81[a] 171	-82[a] 152	[b]-130[a] 156	-70 209	MSE df F p	52432 (1,11) 10.11 **.009**	13801 (4,44) .39 .815	11123 (4,44) 3.80 **.010**
		placebo	481 140	31[a] 93	85[a] 146	[b]93[a] 118	92 189				

Notes:
1. Numbers in each cell of the table represent the mean (top) and standard deviation (bottom).
2. [h] Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.
3. Post-hoc significance test results:
   [a] significant difference between caffeine and placebo changes ($p \leq .05$)
   [b] significant change from baseline ($p \leq .05$)

Table 7: (Continued)

Test	Variable	Drug	Baseline 2200hr	Change from Baseline at:				ANOVA Results			
				0000hr	0200hr	0400hr	0600hr		Drug	Time	Drug x Time
Relative Motion	MRTCAP (msec)	caffeine	8759 1056	53 932	-188 532	-108 645	-788 2553	MSE df F p	845558 (1,11) .07 .794	9172267 (1,13) [h] 1.11 .323	268892 (4,44) .07 .990
		placebo	8822 821	-44 490	-223 649	-90 715	-898 2768				
	PCT CAPT (%)	caffeine	91.1 5.6	2.1 10.4	-2.6 13.4	.5 9.0	-4.7 29.9	MSE df F p	179.07 (1,11) 1.98 .187	1107.75 (1,14) [h] 1.00 .359	60.99 (4,44) 1.17 .338
		placebo	92.7 8.4	-1.0 4.5	-3.6 7.8	-3.6 6.2	-13.5 28.8				
	SDRTCAP (msec)	caffeine	1208 591	705 1593	253 1104	232 803	198 1693	MSE df F p	897723 (1,11) 2.31 .157	749628 (4,44) .61 .656	1943658 (2,26) [h] .34 .743
		placebo	1270 513	31 730	81 817	-73 638	35 1105				
Precision Timing	MRTALL (msec)	caffeine	40 14	-7 12	-7 .12	-2 15	-1 13	MSE df F p	9701 (1,11) .46 .511	6433 (1,16) [h] .66 .484	6010 (1,16) [h] .48 .570
		placebo	52 60	-5 66	6 65	10 50	32 159				
	SDRTALL (msec)	caffeine	62 57	-27 54	-23 50	-16 71	-19 51	MSE df F p	55159 (1,11) .55 .474	9566 (4,44) .27 .896	8639 (3,34) [h] .35 .798
		placebo	83 157	-10 184	21 180	29 168	35 273				
POMS	Anger	caffeine	38.1 2.2	-.3 2.6	-.6 2.2	-.6 2.4	-.2 2.4	MSE df F p	57.76 (1,11) .17 .691	17.62 (2,20) [h] 1.03 .369	15.87 (2,20) [h] 1.41 .267
		placebo	40.1 5.5	-2.5 4.5	-.2 6.2	.2 8.7	-1.9 5.4				
	Confusion	caffeine	35.8 4.1	-1.2 [a] 4.8	.7 [a] 4.0	[b] 2.2 [a] 3.0	[b] 4.0 3.8	MSE df F p	48.89 (1,11) 8.10 **.016**	10.00 (4,44) 13.92 **<.001**	9.26 (4,44) 3.80 **.010**
		placebo	35.2 3.6	[b] 3.2 [a] 2.8	[b] 5.8 [a] 5.2	[b] 8.3 [a] 5.5	[b] 6.5 5.0				
	Depression	caffeine	37.8 1.5	-.7 1.5	-.7 1.5	-.7 1.6	-.7 1.5	MSE df F p	15.62 (1,11) .36 .560	6.60 (2,18) [h] 1.51 .247	5.24 (2,22) [h] 1.40 .268
		placebo	38.5 2.7	-1.1 2.0	.3 2.5	.8 5.3	-.6 2.5				
	Fatigue	caffeine	44.1 7.0	[b] -4.7 [a] 6.2	-1.0 [a] 6.8	[b] 5.5 [a] 8.1	[b] 11.0 8.5	MSE df F p	60.58 (1,11) 21.35 **<.001**	51.39 (3,28) [h] 27.66 **<.001**	16.89 (4,44) 6.18 **<.001**
		placebo	45.8 6.9	[b] 4.8 [a] 3.4	[b] 7.8 [a] 6.5	[b] 15.2 [a] 8.2	[b] 15.8 9.6				
	Tension	caffeine	34.6 3.0	-.6 1.6	-.1 1.7	1.1 3.60	1.4 5.0	MSE df F p	0.08 (1,11) .00 .955	10.97 (2,26) [h] 2.18 .127	4.66 (3,32) [h] .09 .964
		placebo	35.0 3.2	-.6 2.4	.2 4.2	.9 3.9	1.1 3.0				
	Vigor	caffeine	51.8 11.0	-1.7 [a] 9.7	-6.1 [a] 11.0	[b] -12.2 9.6	[b] -14.0 9.7	MSE df F p	181.74 (1,11) 4.44 .059	30.85 (4,44) 35.25 **<.001**	27.27 (4,44) 2.77 **.039**
		placebo	51.6 8.5	[b] -9.1 [a] 5.5	[b] -14.9 [a] 8.2	[b] -18.7 9.7	[b] -17.2 8.9				

Notes: 1. Numbers in each cell of the table represent the mean (top) and standard deviation (bottom).

2. [h] Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.

3. Post-hoc significance test results:

[a] significant difference between caffeine and placebo changes ($p \leq .05$)

[b] significant change from baseline ($p \leq .05$)

Table 7: (Continued)

Test	Variable	Drug	Baseline 2200hr	Change from Baseline at:				ANOVA Results			
				0000hr	0200hr	0400hr	0600hr		Drug	Time	Drug x Time
FPASS	Controlled Turn Duration	caffeine	31.14 31.14	.04 11.25	-1.30 5.79	-2.97 7.76	-3.73 5.81	MSE df	83.90 (1,8)	44.95 (4,32)	46.53 (4,32)
		placebo	26.59 10.87	1.96 5.93	1.41 6.72	3.57 12.71	1.40 7.81	F p	2.85 .130	.24 .911	.65 .629
	Controlled Turn Error	caffeine	12.93 25.63	-.15 41.95	-11.96 25.38	-9.34 26.20	-3.32 17.58	MSE df	2844.87 (1,8)	335.95 (3,24) [h]	509.12 (2,19) [h]
		placebo	14.63 25.88	-10.97 32.17	-14.28 27.37	-13.91 26.01	-1.98 29.29	F p	.09 .778	2.26 .106	.34 .756
	Controlled Turn Start	caffeine	7.72 13.75	-4.79 14.46	-6.72 14.00	-4.71 8.16	-6.20 14.10	MSE df	150.55 (1,9)	92.53 (2,17) [h]	29.91 (4,36)
		placebo	4.88 7.20	3.74 6.39	-3.38 7.62	-1.18 9.91	-1.52 8.99	F p	2.68 .136	2.11 .153	1.57 .203
	Frequency Change Time	caffeine	5.11 3.76	-2.71 4.39	.01 1.45	-3.28 4.66	-1.30 5.22	MSE df	52.63 (1,8)	7.24 (4,32)	23.84 (2,15) [h]
		placebo	4.75 4.94	-1.23 5.59	.24 3.73	-1.03 5.45	-1.04 5.53	F p	.31 .596	2.83 **.041**	.38 .679
	Math Processing	caffeine	7.50 1.27	[b] -1.67 1.71	[b] -1.37 1.13	[b] -.97 1.03	[b] -1.91 [a] 1.58	MSE df	3.57 (1,8)	0.58 (4,32)	1.43 (4,32)
		placebo	6.88 1.15	-.51 1.71	-.08 1.47	-.20 .81	-.11 [a] .92	F p	6.39 **.035**	5.80 **.001**	1.43 .246
	Radar Warning Receiver	caffeine	11.98 7.40	-5.79 8.74	-7.13 7.76	-7.37 8.60	-7.48 9.32	MSE df	156.13 (1,9)	46.01 (4,36)	46.02 (4,36)
		placebo	8.20 10.38	2.43 13.63	-2.90 15.07	.84 10.99	-1.49 8.00	F p	4.54 .062	1.85 .141	1.27 .301
	Surface to Air Missle Alert	caffeine	2.35 .56	-.29 .62	-.59 .69	-.27 .56	.98 4.13	MSE df	24.79 (1,9)	63.83 (1,11) [h]	59.48 (1,12) [h]
		placebo	2.56 .80	-.35 .73	-.34 .93	3.70 13.25	-.23 .96	F p	.35 .571	.78 .422	1.00 .363
	Tracking RMS Alt	caffeine	16.68 11.13	2.48 11.99	-4.89 11.18	-4.69 12.05	3.35 16.85	MSE df	287.59 (1,9)	107.10 (4,36)	100.70 (4,36)
		placebo	18.95 10.36	-6.96 10.75	-2.23 16.35	-.38 16.05	-7.84 13.99	F p	.65 .441	.32 .865	2.52 .058
	Tracking RMS Eas	caffeine	121.44 21.13	4.65 17.04	1.41 20.36	11.57 32.77	.29 35.23	MSE df	3866.7 (1,9)	399.9 (4,36)	662.1 (4,36)
		placebo	137.56 31.31	-6.71 26.32	-5.93 42.86	-8.36 56.52	-14.78 37.84	F p	.75 .410	.57 .689	.44 .782
	Tracking RMS Nor	caffeine	297.66 31.67	-4.02 51.82	-17.83 52.62	-17.85 56.25	12.03 57.34	MSE df	4206.5 (1,9)	1115.5 (4,36)	1317.0 (4,36)
		placebo	283.23 34.52	-7.68 30.43	-9.05 39.44	6.02 52.01	-3.72 44.83	F p	.04 .843	.80 .533	.83 .516

Notes:
1. Numbers in each cell of the table represent the mean (top) and standard deviation (bottom).
2. [h] Huynh-Feldt adjustment was made to the ANOVA degrees of freedom.
3. Post-hoc significance test results:
   [a] significant difference between caffeine and placebo changes ($p \leq .05$)
   [b] significant change from baseline ($p \leq .05$)

Discussion

Although caffeine has been studied extensively (Lieberman, 2001; Smith, 2002), this is the first investigation of the effects of a caffeinated food on performance. Additionally, caffeine has not been studied in a simulated aviation environment. The duration of testing as well as the specific cognitive tests used in this investigation were specifically designed, using the T-matrix approach, to replicate the cognitive demands of the U-2 environment. Additionally, this is the first investigation to assess the effects of caffeine in actual USAF pilots in a mission relevant environment.

The objective of this study was to determine whether moderate doses of caffeine formulated in tube foods could enhance cognitive performance in a laboratory study designed to simulate the cognitive demands of a U-2 mission. Due to the pressure suit required for high-altitude operations, tube foods are the only foods that can be consumed during a U-2 mission. These foods are prepared by the Department of Defense combat feeding program at Natick Labs. The Natick Combat feeding program was tasked to provide the U-2 program with tube foods that enhance performance. The AF Food Service Directorate of Operations requested a study to determine whether the caffeine-containing tube foods produced by Natick Labs enhance vigilance and cognitive performance (Miller, 2002).

In general, the cognitive performance and mood data supported the hypothesis that caffeinated tube food would attenuate some of the performance decrements associated with fatigue (both sleep loss and circadian disruption) in this investigation. Statistically significant improvements under caffeine relative to placebo existed for 7 of the 10 different cognitive tasks and 2 of the 6 flight performance tasks. Though not significant, similar trends were observed in the remaining tasks. The two doses of 200mg of caffeine in the tube food were sufficient in this study to attenuate a majority of the fatigue-induced performance decrements and, in some cases, even improve performance beyond baseline levels, particularly at the 0000 and 0200 time points.

Because of the small sample size, using non-parametric testing would not produce meaningful results for the symptom questionnaire data. Never the less, a notable observation was the increase in reports of abdominal pain and abdominal cramping under the caffeine condition. This is not an unusual symptom with this drug, and it is import to note that only the lowest level of intensity (slight) was indicated by the participants under either condition. In fact, not one of the 43 symptoms was ever reported as greater than 'slight'.

Conclusions

Two doses of 200mg caffeinated tube food maintained cognitive performance representative of U-2 long-duration mission tasks above or near baseline levels for a 10-hour period overnight in a group of 12 qualified USAF pilots. In many cases, performance was improved beyond baseline levels, particularly at the 0000 and 0200 time points. Side effects were sparsely reported and were only 'slight' in severity under both placebo and drug conditions. Based on the results from this investigation, caffeinated tube food may be an effective tool for sustaining cognitive and vigilance during extended and night-time U-2 operations.

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